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1978 - 1980

SURVEY OF THE ATHABASCA AND
SASKATCHEWAN GLACIERS

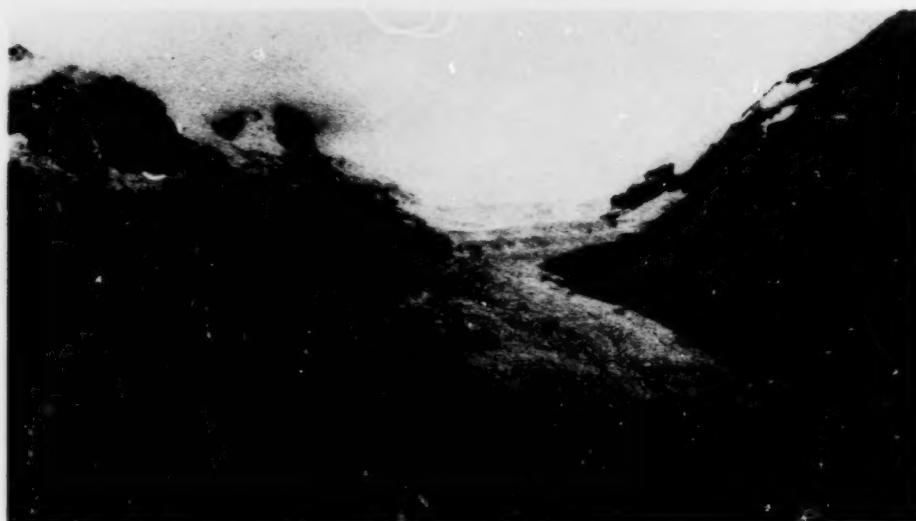
WATER SURVEY OF CANADA
CALGARY DISTRICT OFFICE

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ENVIRONMENT CANADA
WATER SURVEY OF CANADA

1978 - 1980

SURVEY OF THE ATHABASCA AND SASKATCHEWAN GLACIERS



ATHABASCA GLACIER IN 1946

Calgary, Alberta
December, 1982

ABSTRACT

Glacier surveys are carried out in order to establish a chronological record of changes in glacier size, shape and movement rates. Field data provide information from which the glaciologist can determine the relationship between long-term climatological changes, rates of advance or recession, and ablation. Data on glacier melt contribution to streamflow is also obtained.

On the eastern slopes of the Rocky Mountains, glacier inventory data are being obtained by Water Survey of Canada, Calgary and Special Services and Surveys Section, Applied Hydrology Division, Ottawa. The Calgary District of Water Survey of Canada has collected data on toe location and plaque line movement on a number of glaciers since 1945. The Special Services and Surveys Section has recorded volumetric changes of the Athabasca and Saskatchewan Glaciers by use of both aerial and terrestrial photogrammetry since 1959.

This report covers in detail the field data collected by Water Survey of Canada, Calgary, on a biennial basis. The surveys are presently restricted to the Athabasca and Saskatchewan Glaciers, on which the following data is collected:

- (a) Position of the toe (relative to fixed survey points).
- (b) Plaque line movement.
- (c) The ablation of the glacier at the plaque line location.

A brief outline is also given in this report of some previous historical studies and scientific investigations which have been carried out on the Athabasca and Saskatchewan Glaciers by other agencies and individuals.

The present report has been updated to include results of the 1978 and 1980 surveys.

RÉSUMÉ

Les relevés de glaciers sont exécutés afin d'établir un historique des changements dans la grosseur, la forme et les taux de déplacement. Des données prises sur le terrain nous fournissent les renseignements par lesquels le glaciologiste peut déterminer une relation entre les changements climatologiques à long terme, les taux d'avancement et de récession et le retranchement (ablation). On peut aussi déterminer la contribution de la fonte des glaciers au cours d'eau.

Sur le versant est des Montagnes Rocheuses, le département des Relevés Hydrologiques du Canada, à Calgary, et la Section des Services Spéciaux, division de l'Hydrologie Appliquée, à Ottawa, sont en train d'obtenir un inventaire des données sur les glaciers de cette région. Le département des Relevés Hydrologiques à Calgary, a recueilli des renseignements sur les positions de la partie basse (toe) et sur le déplacement de la ligne de plaque de plusieurs glaciers depuis 1945. La Section des Services Spéciaux et la Section des Relevés ont enregistré des changements appréciables de volume à l'aide de photogrammetries aérienne et terrestre depuis 1959.

Cette étude détaillée nous donne l'information acquise sur le terrain par le département des Relevés Hydrologiques du Canada, à Calgary, sur une base bisannuel. Les relevés se limitent présentement aux glaciers Athabasca et Saskatchewan, en voici quelques points:

- (a) La position de la partie basse (toe).
- (b) Le déplacement de la ligne de plaque.
- (c) L'ablation du glacier à la position de la ligne de plaque.

Un bref résumé d'études historiques et de recherches scientifiques exécutées antérieurement sur les glaciers Athabasca et Saskatchewan par d'autres individus ou agences est inclus dans ce compte rendu.

Ce présent rapport a été mis à jour afin d'insérer les résultats de 1978 et 1980.

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INTRODUCTION

Glacier surveys are carried out in order to establish a chronological record of changes in glacier size, shape and movement rates. Field data provide information from which the glaciologist can determine the relationship between long-term climatological changes, rates of advance or recession, and ablation. Data on glacier melt contribution to streamflow is also obtained.

On the eastern slopes of the Rocky Mountains, glacier inventory data are being obtained by Water Survey of Canada, Calgary and Special Services and Surveys Section, Applied Hydrology Division, Ottawa. The Calgary District of Water Survey of Canada has collected data on toe location and plaque line movement on a number of glaciers since 1945. The Special Services and Surveys Section has recorded volumetric changes of the Athabasca and Saskatchewan Glaciers by use of both aerial and terrestrial photogrammetry since 1959.

This report covers in detail the field data collected by Water Survey of Canada, Calgary on a biennial basis. The surveys are presently restricted to the Athabasca and Saskatchewan Glaciers, on which the following data is collected:

- (a) Position of the toe (relative to fixed survey points).
- (b) Plaque line movement.
- (c) The ablation of the glacier at the plaque line location.

A brief outline is also given in this report of some previous historical studies and scientific investigations which have been carried out on the Athabasca and Saskatchewan Glaciers by other agencies and individuals.

The present report has been updated to include results of the 1978 and 1980 surveys.

Further information on previous surveys conducted by Water Survey of Canada, Calgary District, may be obtained by writing to:

Mr. G. H. Morton
Regional Chief, Alberta District
Water Resources Branch
Inland Waters Directorate
Bag 2909, Postal Station 'M'
Calgary, Alberta
T2P 2M7

BACKGROUND

DESCRIPTION AND LOCATION OF THE GLACIERS (See Plates 1 and 2 in Appendix 1)

Athabasca Glacier

Athabasca Glacier is fed by the Columbia Icefield. It is ideal for most studies, having simple geometric shape and accessibility. The glacier leaves the main ice field at elevation 2 600 metres, descends in a series of three ice falls over a distance of 2 kilometres, and continues as a gently-sloping tongue of roughly uniform width to a blunt terminus at approximate elevation 1 950 metres. The distance from the foot of the lowest ice fall to the toe is approximately 300 metres, with an average width of 700 metres. The elevation over this reach decreases from 2 280 metres to 1 950 metres at an average slope of 3 to 5 degrees, increasing to 15 degrees at the toe. The northwest corner of the toe terminates in a glacial lake. In the 1.6 kilometre reach below the last ice fall, the glacier depth along the centre line ranges from 240 to 320 metres. Below this there are two rises in the bed and the ice thins rapidly near the terminus.

Athabasca Glacier is deeply crevassed near the valley walls and in two small areas, one located immediately above the terminus and the second about 1.6 kilometres up the glacier, corresponding to the rises in the bed. There are two tributary valley glaciers on the southeast side, neither of which is in contact at this time.

Streamflow records from 1948 on are available from a streamflow station located below the outlet from the glacial lake at the glacier terminus. The lake received runoff from Athabasca Glacier, two tributary glaciers, and a glacier on the north side of Mt. Athabasca.

Saskatchewan Glacier

Saskatchewan Glacier is the largest of the six principal tongues of the Columbia Icefield and is the source of the North Saskatchewan River in Banff National Park. The glacier is a geometrically simple ice stream emerging from the ice field at approximate elevation 2 600 metres. It flows roughly 10 kilometres to a terminus at approximate elevation 1 800 metres. The main glacier is about 1.6 kilometres wide over the upper 4 kilometres, and tapers to a width of 500 metres at the terminus.

The usual firn limit lies at the junction of the main glacier and the tributary tongue. The total area of Saskatchewan Glacier and its firn field is about 37 square kilometres, of which the accumulation area embraces approximately 68 per cent.

METHODS OF SURVEYING AND CALCULATION

Movement of Toe

Two methods have been employed for computing the movement rates during the course of the glacier surveys. Prior to 1960, the yearly advance or recession of the toe of any glacier was determined by plotting the position of the toe for the last two surveys on a plan, determining the area between the resulting lines, and dividing the area by half the total length of the lines. The surveys have normally been conducted on a biennial basis, the yearly advance actually being an average over the two-year period between surveys.

In 1960 a standard base line distance was adopted and all previous calculations were revised. The base line distance used for an individual glacier is the distance across the glacier at some point above the toe representative of an average width which will remain fairly constant from year to year. All figures in this report are revised figures except where noted.

Advance of Plaque Line

A plaque line consists of twelve to twenty-five sheet metal plates placed on the surface of the ice at regular intervals in a straight line across the glacier. The line is laid out approximately at right angles to the direction of flow. The plates are about 20 centimetres square, numbered and indicating the year, and fastened to the ice by having two corners bent down and embedded in the ice. The line is located in the same position each year by reference to fixed points on the adjacent valley walls and the position of each individual plaque is determined by stadia survey techniques.

Earlier survey plaques are found and surveyed. The advance of each plaque from its original position is determined and thus the mean advance of the ice surface at the plaque line location is calculated.

PAST SURVEYS AND INVESTIGATIONS

ATHABASCA GLACIER

Athabasca Glacier has been visited and photographed since 1903, but no detailed measurements or studies were carried out prior to 1945 when Water Survey of Canada began plaque line and toe recession measurements. Major scientific visits and studies by agencies other than Water Survey of Canada, Calgary District, are listed below in chronological order.

- 1903 — Sketched (Stutfield and Collie, 1903).
- 1908 — Photographed for the Canadian Alpine Journal (Schaffer, 1908).
- 1919 — Mapped and photographed (Thomson, 1920; also Boundary Commission, 1924).
- 1922 — Photographed for the Canadian Alpine Journal (Field, 1949).
- 1953 — "Postglacial Environments in the Canadian Rocky Mountains" (Heusser, 1956). Heusser found that Athabasca Glacier reached its maximum advance around 1714. Withdrawal began in 1721 and again in 1744. The glacier re-advanced in the first half of the 19th century almost to its 1714 position. Withdrawal began again in 1841 and in 1866. Recession has continued, with minor fluctuations, and recessional moraines denoting periods of pause were formed in 1900, 1908, 1925 and 1935. The total recession of the glacier between 1721 and the present is approximately 1 200 metres.
- 1959 — "Triangulation Survey of the Athabasca Glacier, July, 1959", Special Services and Surveys Section of Water Survey of Canada (Reid, 1961) undertook the first triangulation survey of Athabasca Glacier in order to establish permanent horizontal and vertical control points around the perimeter for the preparation of topographic maps of the glacier by aerial survey. A contour map was prepared from the survey results.
- 1959-61 — "Variations in Velocity of Athabasca Glacier with Time" (Paterson, 1964). Paterson measured surface velocities on the Athabasca Glacier ablation area between August 1960 and July 1961. He found that

over the winter period of September to April, surface velocities were steady, with only a slight increase of 1 or 2 per cent due to the accumulation of ice and snow over winter. Summer velocities, however, were approximately 25 per cent greater than winter velocities despite ablation of the surface and corresponding reduction in ice depth. Paterson concluded that the increased summer velocities were due to more efficient basal slip of the glacier by ice melt and precipitation. In an attempt to verify this, Paterson measured the glacier surface movement at several points over three consecutive weekly periods in July and August of 1960. The rates of flow were then correlated to the mean daily discharges of the glacial lake which were assumed to reflect changes in glacier bed discharge. The indications were that short-term variations in velocity during summer were dependent upon glacier bed discharge and hence short-term climatological changes.

- 1962 - Aerial and terrestrial mapping (Konecny, 1964). While a second aerial survey was being carried out, a terrestrial photogrammetric survey of Athabasca Glacier was made by Dr. Konecny of the University of New Brunswick. Thus it was possible to compare directly the relative costs and accuracy of the two survey methods. It was found that while aerial photogrammetry provides a more satisfactory map, terrestrial photogrammetry is more economical and perfectly adequate for mapping small glaciers over the ablation area. Resurveys by terrestrial means from the same survey stations and with the same orientation are also more convenient.
- 1965 - Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section.
- 1967 - Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section.
- 1968 - Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section. The survey was specifically carried out to determine the volumetric change occurring over a one-year period instead of the standard two-year interval.
- 1969 - Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section.

- 1971 — Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section.
- 1973 — Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section.
- 1975 — Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section.

SASKATCHEWAN GLACIER

Saskatchewan Glacier, while not surveyed and studied as extensively as Athabasca Glacier, has received considerable attention. Major scientific visits and surveys, in addition to Water Survey of Canada Calgary District surveys detailed starting on page 10, are listed below in chronological order.

- 1912 — Photographed for the American Alpine Club Collection by Mitchell (Field, 1949).
- 1919 — Photographed for the Canadian Alpine Journal (Thomson, 1920).
- 1922 — Photographed by Field (Field, 1948).
- 1923 — Photographed for Canadian Alpine Journal by Thorington (Thorington and Ladd, 1924).
- 1924 — Photographed for National Geographic Magazine by Harmon (Freeman, 1925).
- 1953 — "Postglacial Environments in the Canadian Rocky Mountains" (Heusser, 1956). Heusser could find no evidence of activity on Saskatchewan Glacier in the 18th century. Maximum surges occurred in 1807, 1813, and 1893. The total recession from the maximum position of the toe to the present location is approximately 1 700 metres.
- 1952-54 — "Mode of Flow of Saskatchewan Glacier, Alberta, Canada" (Meier, 1960). The work of this study was directed towards the measurement of velocity both on the surface and at depth, the surface and bedrock topography, ablation, and structures produced by the flow. The field data was used to test the various theories of glacier flow and derive new calculations on the flow of valley glaciers. Meier's velocity measurements over short-term intervals confirmed Paterson's findings on the Athabasca Glacier. The range of fluctuations in velocity about the mean is inversely proportional to the logarithm of the time interval between measurements. Twelve-hour time intervals can give velocity measurements varying 100 per cent or more from a mean.
- 1963 — Terrestrial mapping, Water Survey of Canada Special Services and Surveys Section.

- 1965 - Terrestrial mapping, Water Survey of Canada
Special Services and Surveys Section.
- 1967 - Terrestrial mapping, Water Survey of Canada
Special Services and Surveys Section.
- 1969 - Terrestrial mapping, Water Survey of Canada
Special Services and Surveys Section.
- 1971 - Terrestrial mapping, Water Survey of Canada
Special Services and Surveys Section.
- 1973 - Terrestrial mapping, Water Survey of Canada
Special Services and Surveys Section.
- 1975 - Terrestrial mapping, Water Survey of Canada
Special Services and Surveys Section.

MISCELLANEOUS GLACIER SURVEYS

Several glaciers on the east slopes of the Rocky Mountains, in addition to Athabasca and Saskatchewan Glaciers, were surveyed for various periods of time by the Calgary District office of Water Survey of Canada. Surveys were initiated in 1945 and conducted annually until 1960 when a biennial survey time period was adopted. The period of record for each glacier is shown below as well as the reasons for termination of surveys.

(a) Angel Glacier:

Surveyed in 1946 and 1947, but further surveys were not carried out when the toe of the glacier broke away from the main body of the ice.

(b) Balfour Glacier:

Was reconnoitered in 1945 but found to be a hanging glacier and unsuitable for study.

(c) Bow Glacier:

Was reconnoitered in 1945 but found to be a hanging glacier and unsuitable for study.

(d) Freshfield Glacier:

Surveyed six times between 1947 and 1954 but was discontinued due to poor accessibility.

(e) Lyell Glacier:

Reconnoitered in 1947 and found unsuitable for survey.

(f) Peyto Glacier:

Surveyed twelve times between 1945 and 1962 but was discontinued when the glacier receded into a hanging condition.

Detailed studies were initiated on Peyto Glacier in 1965 by the Glaciology Section of the Canadian contribution to the International Hydrological Decade Program. Mass, energy, and water balance studies have been carried out by the Glaciology Division of the Water Resources Branch, Department of Environment.

(g) Victoria Glacier:

Surveyed eight times between 1945 and 1954 until the toe became hidden by thick deposits of moraine.

(h) Yoho Glacier:

Reconnoitered in 1945 but a decision was made against surveys since a hanging condition appeared imminent.

1978 AND 1980 SURVEY RESULTS

The 1978 Calgary District survey was conducted over three days, August 14, 15 and August 22 on the Saskatchewan and Athabasca Glaciers. The survey party members were Messrs. L. Warner, R. Barnettson, R. Kerjer, C. Robinson, J. Anderson and T. Davis. The 1980 survey was conducted July 28, 29 and 30 by Messrs. J. Anderson, J. Lines, C. Robinson and P. Holinshead.

SASKATCHEWAN GLACIER SURVEY

The Saskatchewan Glacier plaque line survey was discontinued after 1976 because the survey control points had been destroyed by rock slides. In addition, the plaque line is presently too near the toe to provide any meaningful results.

Plates 3A and 3B (Appendix 1) depict the 1978 and 1980 toe surveys, respectively. A standard base line width of 507 metres is used to calculate the toe movement between surveys on the Saskatchewan Glacier. Using the area between the 1976 and 1978 toe delination, the total recession for the two-year period was 62 metres, or 31 metres per year. The total recession for the two-year period from 1978 to 1980 was 70 metres, or 35 metres per year. A summary of survey data collected by Water Survey of Canada on the Saskatchewan Glacier is tabulated in Table 1. A chronological record of toe recession is illustrated on Plate 4 (Appendix 1) and the five-year moving mean has been superimposed to demonstrate the trend since 1945.

TABLE 1

SASKATCHEWAN GLACIER
Plaque Line Movement and Toe Recession 1945 to 1980

Period of Record	Advance of 1961 Plaque Line (m/yr.)	Rate of Toe Recession (m/yr.)
1945-46		47
1946-47		77
1947-48		45
1948-49		48
1949-50		49
1950-52		38
1952-54		46
1954-56		36
1956-58		40
1958-60		33
1960-62	25	41
1962-64	27	27
1964-66	27	13
1966-68	31	20
1968-70	38	8
1970-72	40	2
1972-74	56	21
1974-76	20	17
1976-78	*	31
1978-80		35

* discontinued

ATHABASCA GLACIER SURVEY

Twenty numbered plaques were placed along the plaque line during the 1978 survey. As in previous years, difficulty was encountered in establishing an evenly spaced plaque line because of the deeply crevassed nature of the glacier. The search for previous years' plaque yielded 15 from the 1976 survey and these are shown plotted on Plate 5A (Appendix 1), together with the results of the 1978 toe survey.

Table 2 summarizes the rate of advance of the 15 plaques from the 1976 survey. The average rate of advance for the period 1976-1978 is calculated as 36 metres per year.

TABLE 2

ATHABASCA GLACIER Advance of the 1976 Plaque Line

Plaque No.	Advance (m)	Plaque No.	Advance (m)
3	85	14	71
4	75	15	72
5	78	16	68
6	83	17	68
10	78	18	68
11	75	19	64
12	74	20	61
13	73		

Plate 5B (Appendix 1) depicts the 1980 plaque line and toe survey. Twenty-two plaques were set on the plaque line and thirteen plaques from the 1978 survey were located. The plaque line advance averaged 28 metres per year between 1978 and 1980 and the advance of each plaque is tabulated in Table 3.

TABLE 3

ATHABASCA GLACIER
Advance of the 1978 Plaque Line

Plaque No.	Advance (m)	Plaque No.	Advance (m)
1	52	15	55
5	63	16	54
6	63	17	56
9	60	18	51
12	61	19	51
13	60	20	48
14	58		

A standard base line width of 547 metres has been adopted for use in calculating the toe recession of the Athabasca Glacier. Using the area between the 1976 and 1978 toe delineations, the average recession of the toe was 14.8 metres, for an average yearly rate of 7.4 metres. The total recession for the two-year period 1973 to 1980 was 11.2 metres, or 5.6 metres per year.

The complete record of plaque line movement and toe recession collected by the Water Survey of Canada is tabulated in Table 4.

TABLE 4

ATHABASCA GLACIER
Plaque Line Movement and Toe Recession 1945 to 1980

Period of Record	Advance of Plaque Line (m/yr.)		Rate of Toe Recession (m/yr.)
	Upper	Lower	
1945-46		20	24
1946-47		19	27
1947-48		15	25
1948-49		15	27
1949-50		13	33
1950-52		14	24
1952-54		14	19
1954-56		15	20
1956-58		19	36
1958-60		19	37
1960-62	32	19	0.6
1962-64	34	22	17
1964-66	35	*	2
1966-68	39		9
1968-70	37		12
1970-72	37		3
1972-74	33		3
1974-76	37		3
1976-78	36		7.4
1978-80	28		5.6

* discontinued

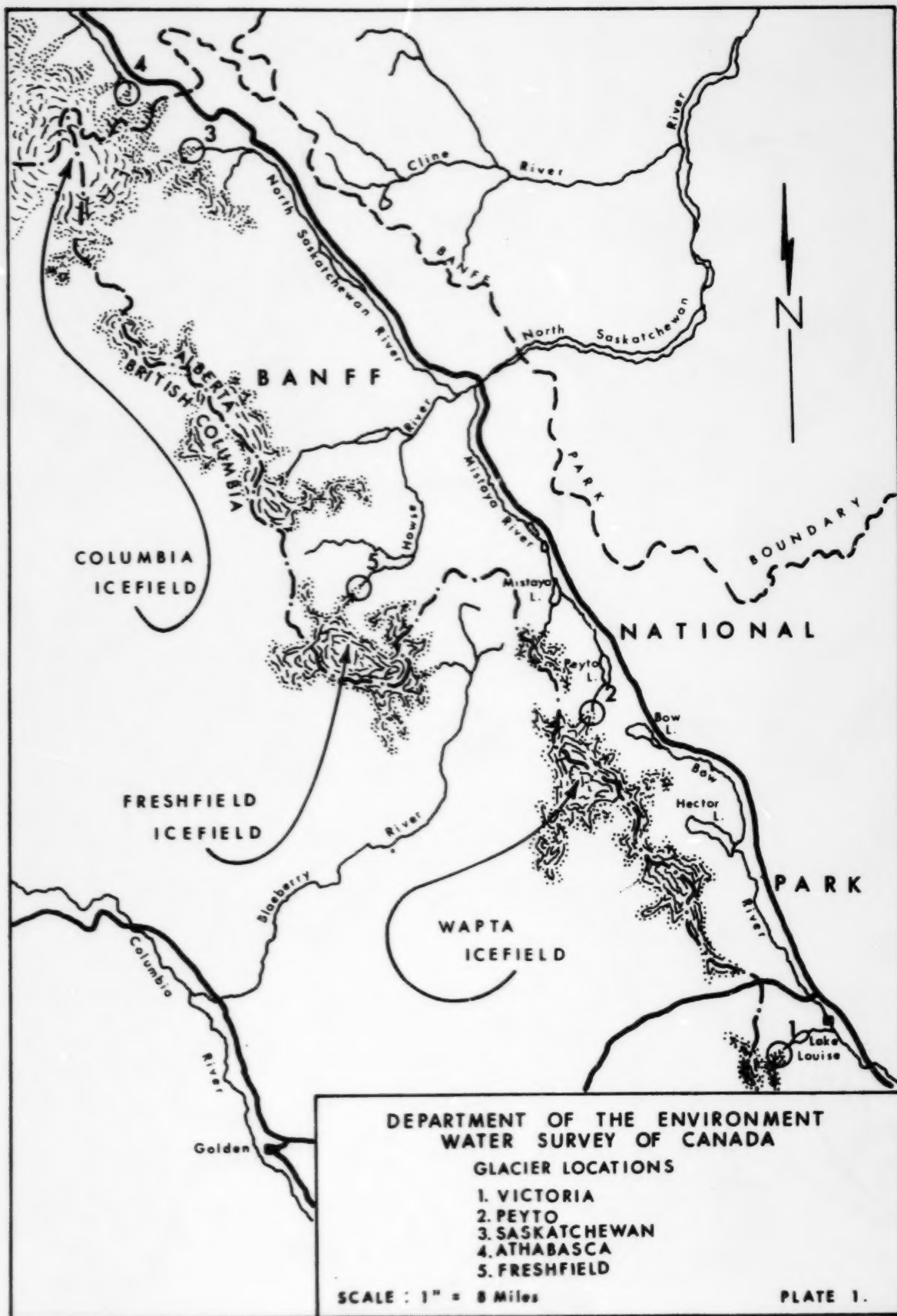
The plaque line elevation at the time of each survey is shown on Plate 6 (Appendix 1). A chronological record of toe recession has been plotted with the five-year moving mean superimposed on Plate 7 (Appendix 1).

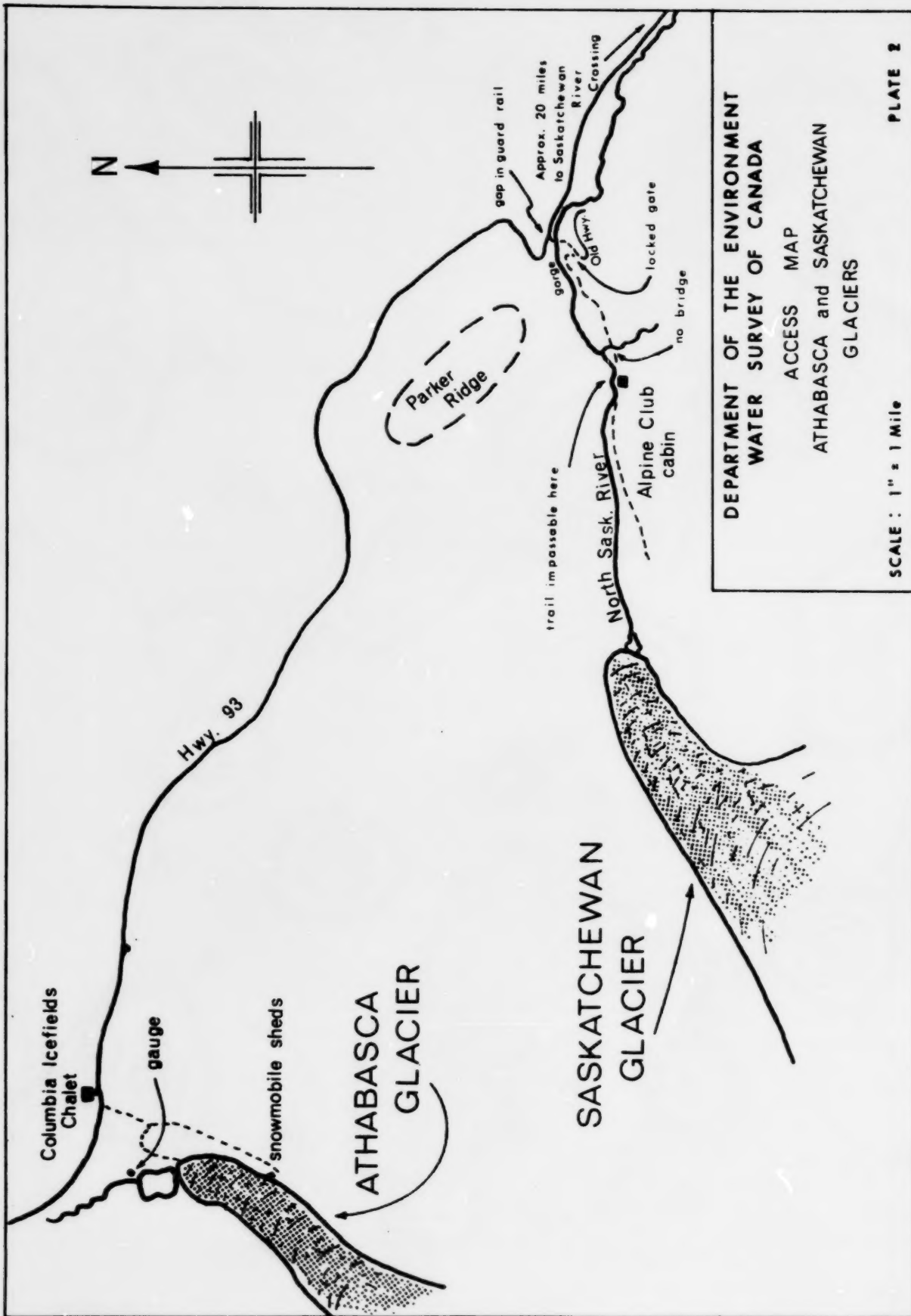
SUMMARY

The chronological record of toe recession for the Saskatchewan and Athabasca glaciers is shown graphically on Plates 4 and 7 (Appendix 1), respectively. The five-year moving mean of the rate of recession has been superimposed to smooth out the fluctuations and demonstrate more clearly the underlying trends.

For comparative and interpretive purposes, the ten-year moving means of mean annual temperature and precipitation at Banff are shown graphically on Plate 8 (Appendix 1). Photographs of the Saskatchewan and Athabasca glaciers are shown on Plates 9 and 10 (Appendix 1) respectively, as they appeared in 1980.

APPENDIX 1



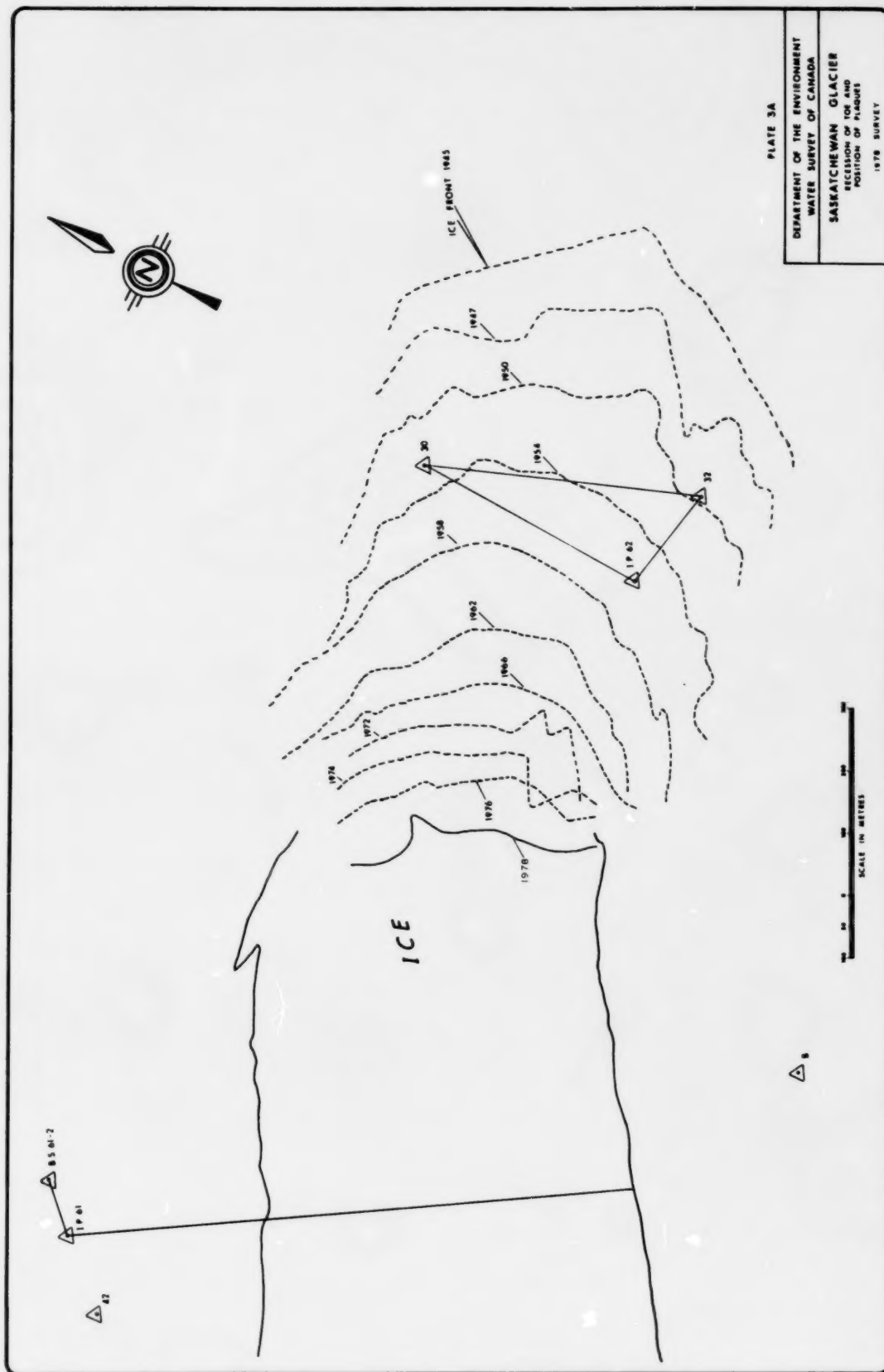


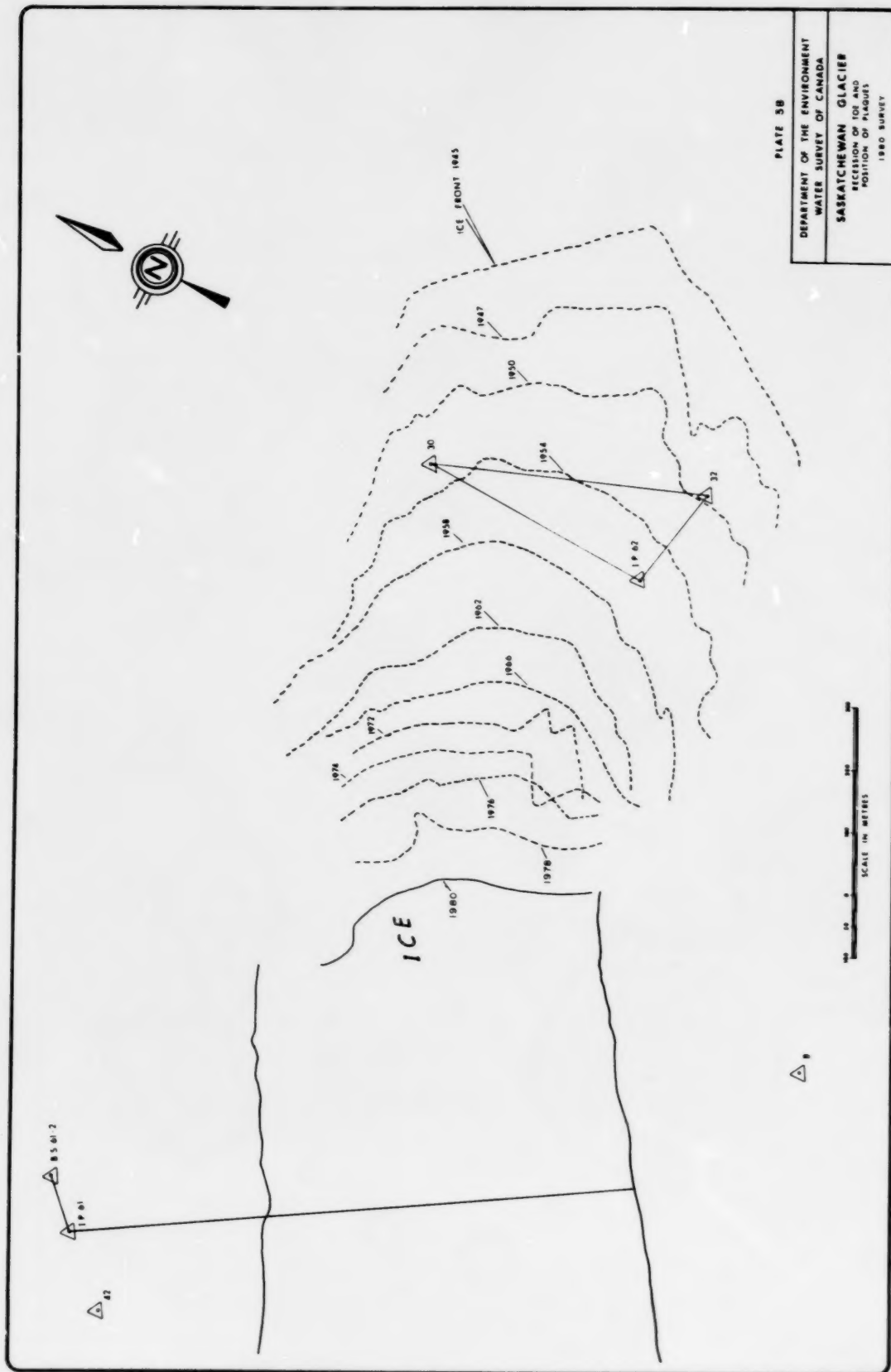
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ACCESS MAP
ATHABASCA and SASKATCHEWAN
GLACIERS

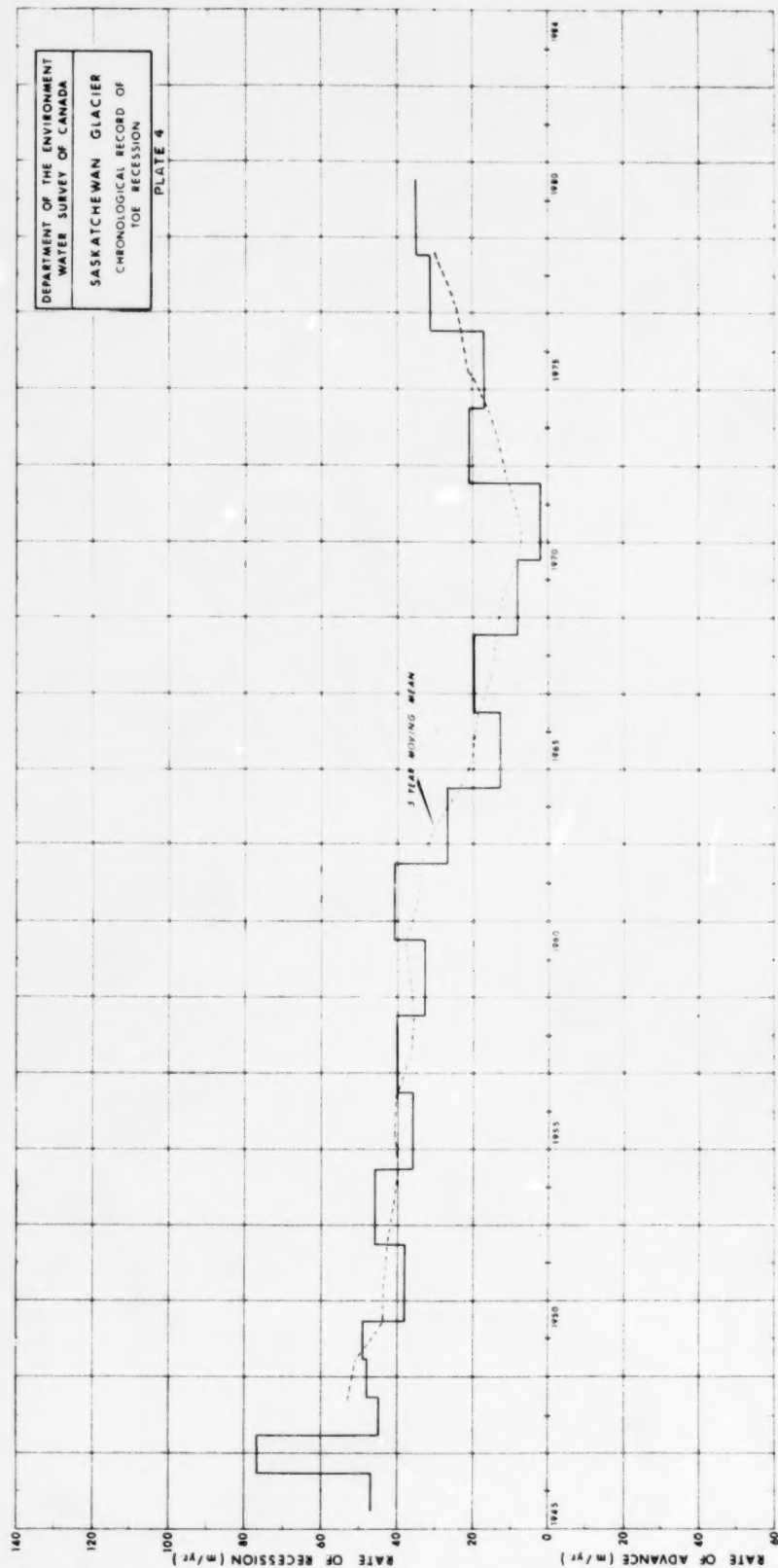
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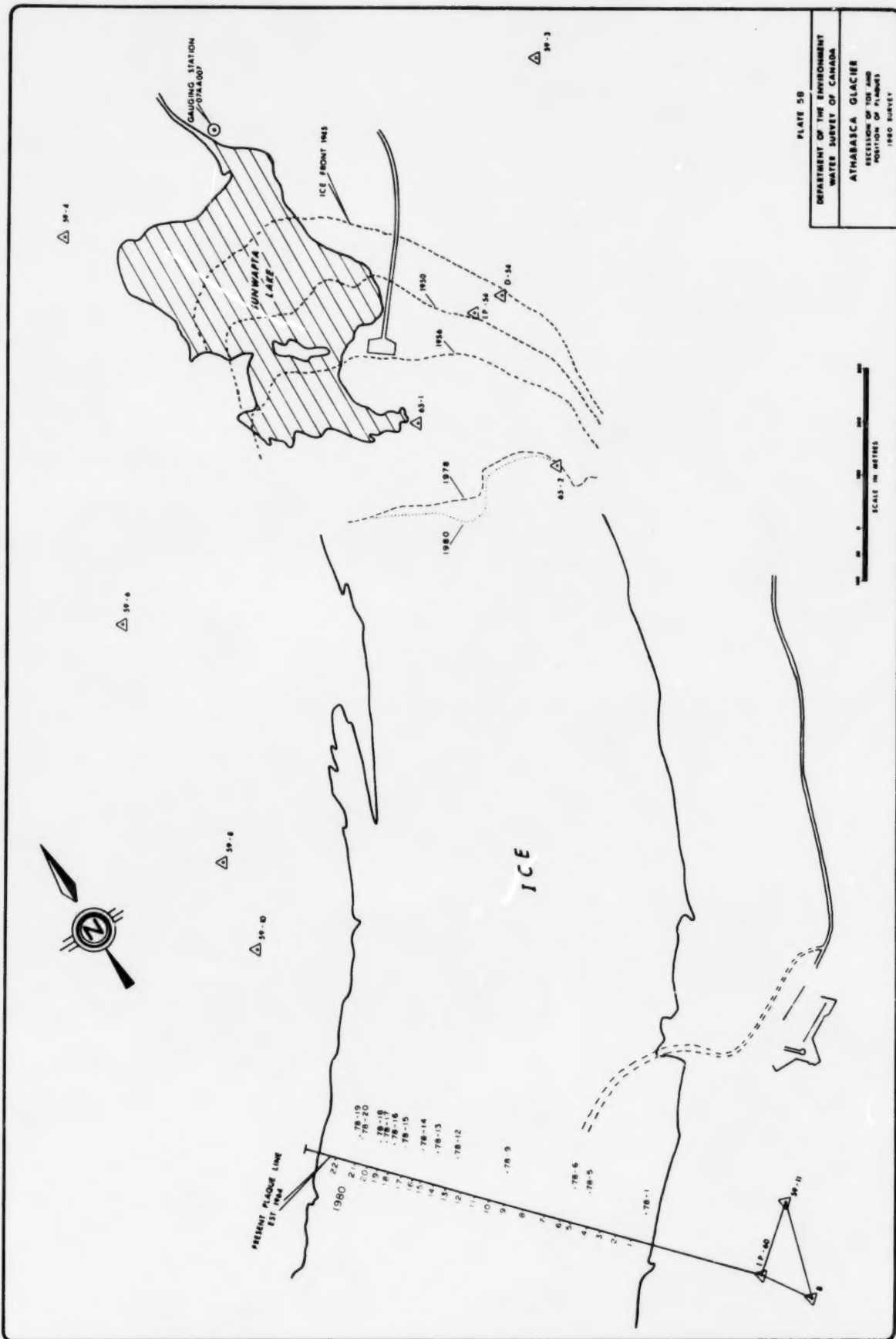
PLATE 2

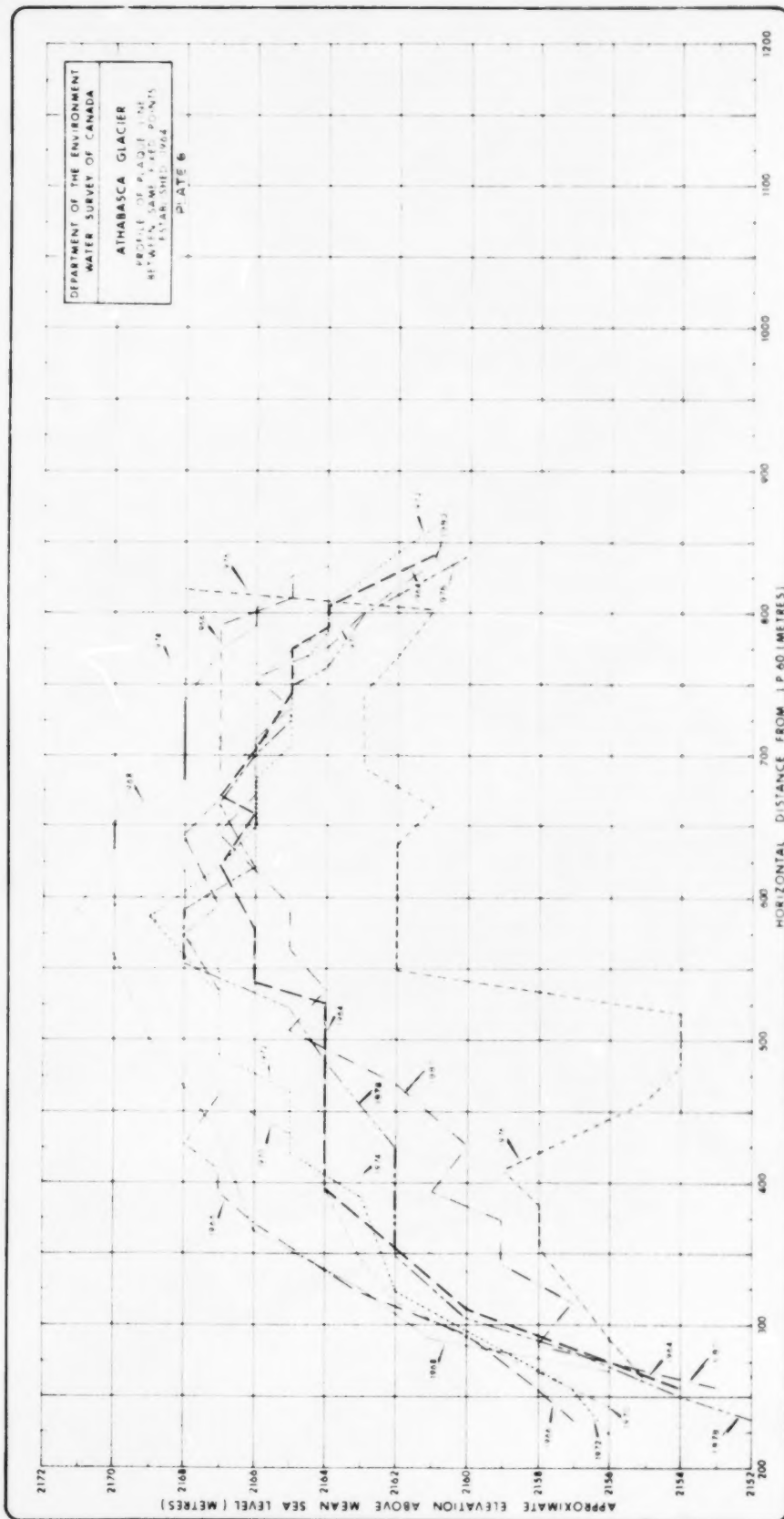




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WATER SURVEY OF CANADA
SASKATCHEWAN GLACIER
CHRONOLOGICAL RECORD OF
TOE RECESSION
PLATE 4



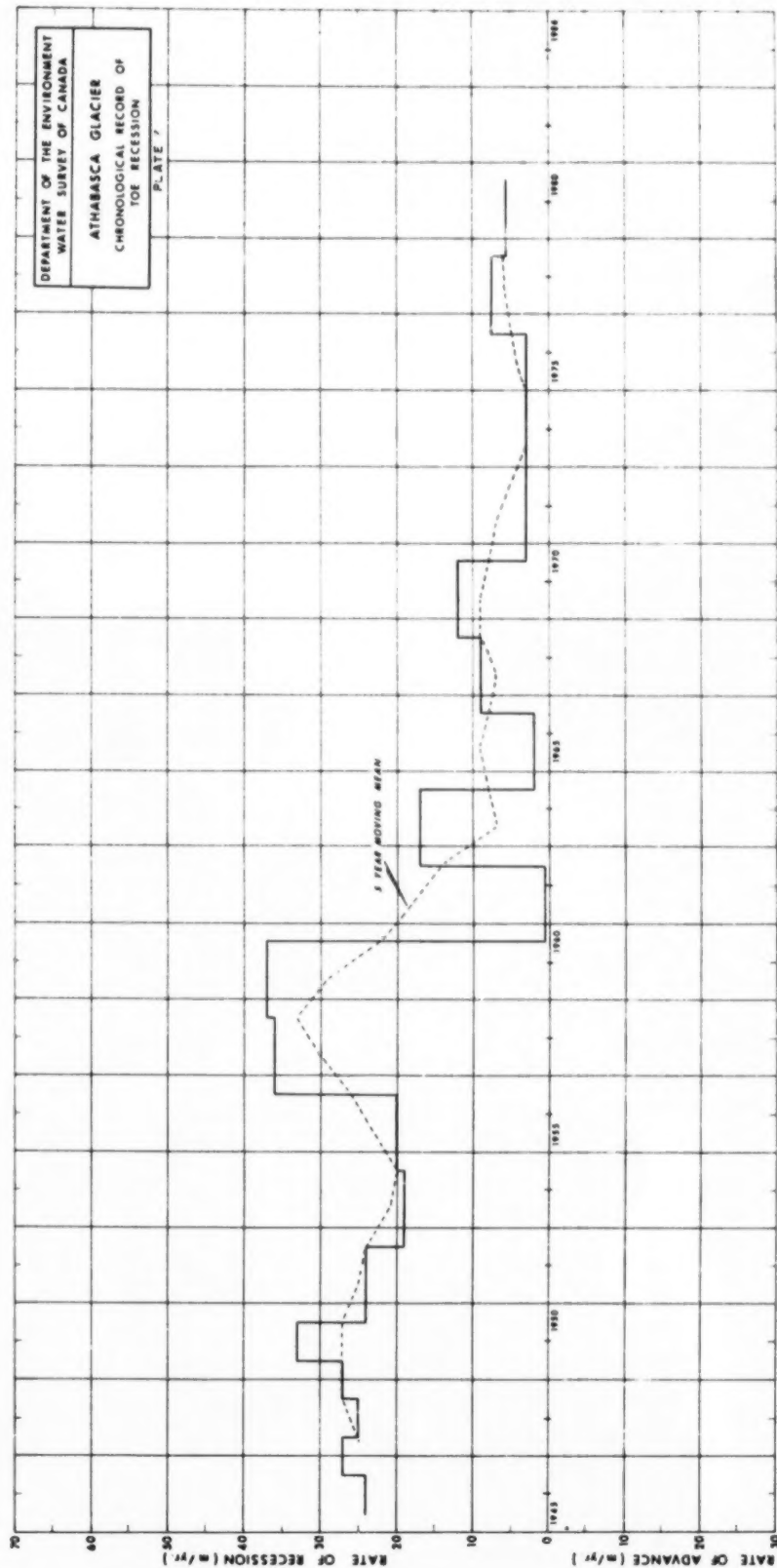




DEPARTMENT OF THE ENVIRONMENT
WATER SURVEY OF CANADA

ATHABASCA GLACIER
CHRONOLOGICAL RECORD OF
TOE RECESSION

PLATE 7



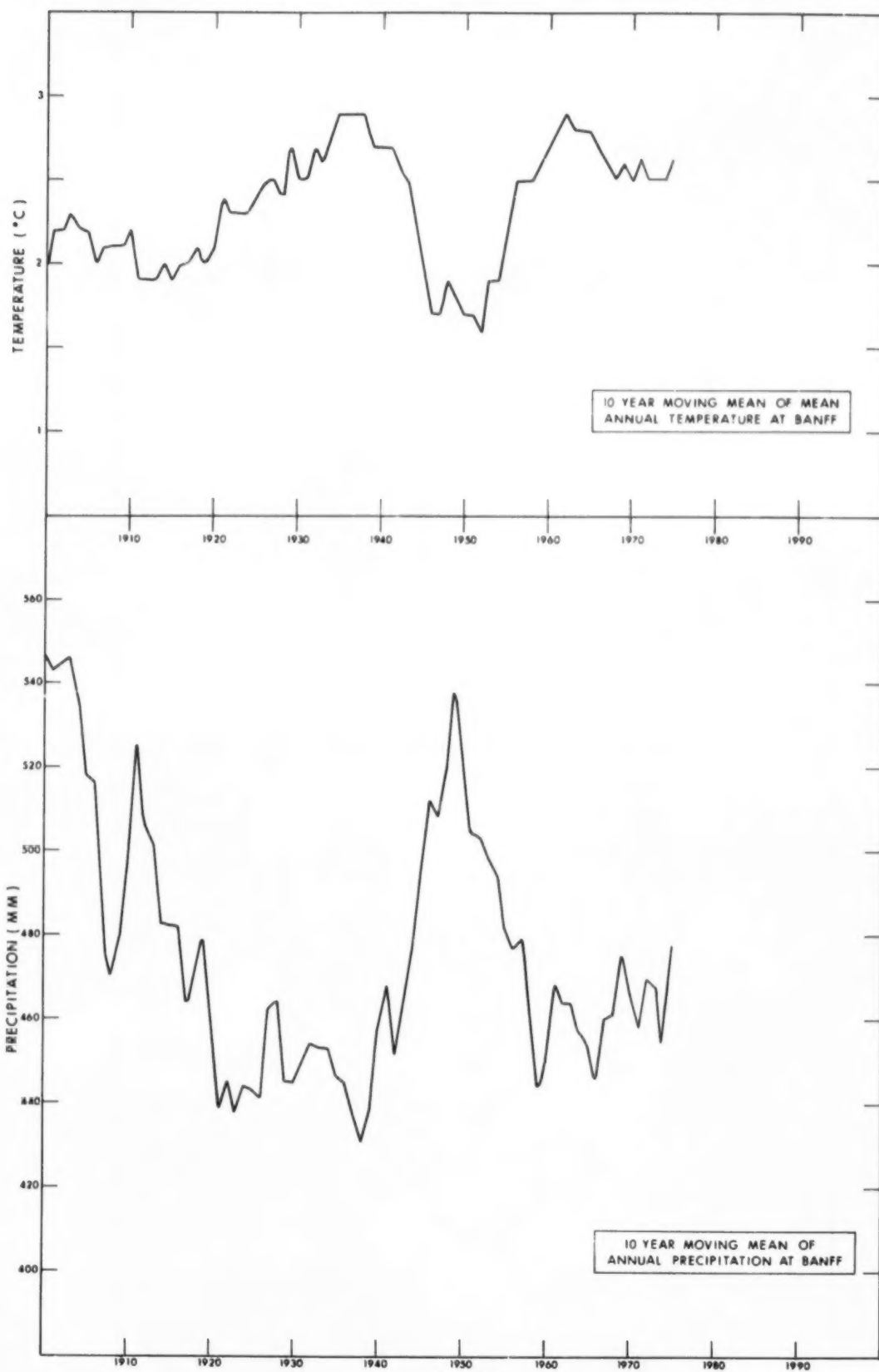


PLATE 8



Saskatchewan Glacier, July 29, 1980



Saskatchewan Glacier from Parker's Ridge, July 29, 1980



Athabasca Glacier, July 30, 1980.



APPENDIX 2

BIBLIOGRAPHY

- Ahlmann, H. W. (1953): *Glacier Variations and Climatic Fluctuations*. New York: American Geographical Society (51 pages).
- Boundary Commission (1924): See Report of Commission Appointed to Delimit the Boundary Between the Provinces of Alberta and British Columbia.
- Collier, E. P. (1958): *Glacier Variations and Trends in Runoff in the Canadian Cordillera*. Union Géodésique et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Assemblée Générale de Toronto. (pp. 344-357).
- Field, W. O. (1924): "Mountaineering on the Columbia Icefield". *Appalachia*, 16 (1924), pp. 144-154.
- Field, W. O. (1949): "Glacier Observations in the Canadian Rockies". *Canadian Alpine Journal*, Vol. 32 (1948), pp. 99-114.
- Field, W. O., and Heusser, C. J. (1954): "Glacier and Botanical Studies in the Canadian Rockies". *Canadian Alpine Journal*, Vol. 37 (1953), pp. 127-140.
- Freeman, L. R. (1925): "The Mother of Rivers". *National Geographic Magazine*, Vol. 47, pp. 377-446.
- Heusser, C. J. (1956): "Postglacial Environments in the Canadian Rocky Mountains". *Ecol. Mono.*, Vol. 26, pp. 263-302.
- Konecny, G. (1964): "Glacial Surveys in Western Canada". *Photogrammetric Engineering*, Vol. 30, No. 1, pp. 64-82.
- Macfarland, W. T. (1946): "Glacier Investigations in Banff, Yoho, and Jasper National Parks". *Canadian Alpine Journal*, Vol. 29, pp. 265-273.
- Meier, M. F. (1960): "Mode of Flow of Saskatchewan Glacier, Alberta, Canada". U.S. Geological Survey Professional Paper 351 (70 pages).
- National Research Council (1966): *Canadian Journal of Earth Sciences*, Vol. 3, No. 6 (November, 1965). A special issue containing papers presented at a Symposium on Glacier Mapping, Ottawa, 1965 (915 pages).
- Nye, J. F. (1960): "The Response of Glaciers and Ice Sheets to Seasonal and Climatic Changes". *Proceedings of Royal Society*, Vol. 256, No. 1287, pp. 559-584.
- Paterson, W. S. B., and Savage, J. C. (1963): "Borehole Measurements in the Athabasca Glacier". *Journal of Geophysical Research*, Vol. 68, No. 15, pp. 4521-4536.

- Paterson, W. S. B., and Savage, J. C. (1963): "Geometry and Movement of Athabasca Glacier". *Journal of Geophysical Research*, Vol. 68, No. 15, pp. 4513-4520.
- Paterson, W. S. B. (1964): "Variations in Velocity of Athabasca Glacier With Time". *Journal of Glaciology*, Vol. 5, No. 39 (October), pp. 277-285.
- Reid, I. A. (1961): "Triangulation Survey of the Athabasca Glacier, July, 1959". Department of Northern Affairs and National Resources, Water Resources Branch, Ottawa. (20 pages).
- Schaffer, M. T. S. (1908): "Untrodden Ways". *Canadian Alpine Journal*, Vol. 1, pp. 228-294.
- Stutfield, H. E. M., and Collie, J. N. (1903): *Climbs and Exploration in the Canadian Rockies*. London, New York, and Bombay: Longmans, Green, and Co. (343 pages).
- Thomson, A. S. (1920): *Canadian Alpine Journal*, Vol. 11, p. 138.
- Thorington, J. M. (1938): "Notes on Saskatchewan and Freshfield Glaciers". *American Alpine Journal*, Vol. 3, pp. 219-220.
- Thorington, J. M., and Ladd, W. S. (1924): "A Mountaineering Journey to the Columbia Icefield". *Canadian Alpine Journal*, Vol. 14, pp. 34-46.

POOR

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